REMARKS

Entry of this Preliminary Amendment is respectfully requested prior to the first Office Action and prior to the calculation of the filing fee for the subject application. After entry of this Amendment, claims 1 - 22 are pending in the application. Claims 1 - 22 have been amended.

A hand-written, corrected copy of the specification is enclosed showing the changes which have been made to the specification as required by Section 608.01(Q) and 714.20(1) of the Manual of Patent Examining Procedure. The Substitute Specification filed herewith has been amended to utilize idiomatic English, correct minor typographical and grammatical errors and to conform the application to current United States Patent practice. The Substitute Specification includes no new subject matter; but does include the same changes handwritten in red in the attached, corrected, original specification.

It is submitted that this Amendment has antecedent basis in the application as originally filed, including the specification and claims, and that this Amendment does not add any new subject matter to the application. Consideration of the application as amended is requested. It is submitted that this Amendment places the application in suitable condition for allowance; notice of which is requested.

If the Examiner feels that prosecution of the present application can be expedited by way of an Examiner's Amendment, the Examiner is invited to contact the Applicant's attorney at the telephone number listed below.

Respectfully submitted,

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Dated: September 3, 2004
WMH/dge

PCT/DE03/00763

10/506696

DT09 Rec'd PCT/PTO 03 SEP 2004

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Electrode element for plasma torches as well as a method for the production of same

## BACKGROUND

The invention relates to an electrode element for plasma torches as well as a production method for such electrode elements. Such an electrode element is particularly suitable for plasma cutting in which oxygen is used as a plasma gas.

Such electrodes are very highly stressed thermally and electrically when used in plasma torches such that they only achieve limited service lives, and an expensive replacement of electrodes is required in more or less long time intervals.

In particular, the high thermal load caused by temperatures of up to 50 000 K requires an appropriate design and a suitable selection of the materials used for such an electrode.

Thus, up to now for plasma cutting using oxygen as a plasma gas, electrodes substantially made up of hafnium are employed

with a melting temperature in the range of 2220 °C. Hafnium has a low work function in contrast to many other electrically conducting metals such that it is especially appropriate for the application.

As a rule, such pencil-shaped hafnium electrodes having a copper socket are used, and at the same time use is made of the high thermal and electrical conductivity of copper.

However, having such a formation the electrical anodic corrosion (electromigration) and diffusion which increases the transition resistance then between the hafnium and copper, has to be kept small.

In particular during plasma cutting with oxidizing gases as that is the already mentioned oxygen, oxidation occurs with the copper such that this has a bad influence on the thermal conductivity and the electrical transition resistance between the copper and hafnium.

Due to the high anodic corrosion and oxidation it follows an increased power conversion at the boundaries between the hafnium and the copper such that the aging processes proceed in an accelerated manner.

Because of the enhanced formation of copper oxide on the copper sheath at higher temperatures in close proximity of the hafnium core in addition the work function of copper is decreased, and accordingly copper electrons are also allowed to emit out of it. Because of that it may result in local fusing of the copper, and accordingly in an unserviceability of such a plasma electrode.

According to the prior art, silver or a silver alloy are used to counteract these problems. Silver has also good thermal and

electrical conductivities as well as a higher work function. In particular, the oxide formation with silver is less in contrast to copper at higher temperatures.

An equivalent solution is described in EP 0 980 197 A2. On that occasion, a copper holder shall find use into which a silver sleeve made of a selected silver alloy and having a closed bottom facing into the interior of the copper holder is pressed into a receptacle formed as a blind hole.

Then, a pencil-like electrode made of hafnium is again pressed into this silver sleeve.

Such a structure has several disadvantages. This concerns the expensive production, on the one hand, during which the individual elements have to be fabricated separately and partially by metal cutting. The three individual parts have then to be joined together into one element wherein high demands have to be met upon joining and handling because of the relatively small-sized silver sleeve and the hafnium pin. In addition, mechanical pressing of the silver sleeve and the hafnium pin has to be carried out very carefully.

Nevertheless, merely a locally limited contact between the copper, silver and hafnium can be achieved such that in particular these spot-shaped contacts have an adverse effect with respect to the anodic corrosion already mentioned, and of course the thermal conductivity is correspondingly negative influenced as well.

Accordingly, with such a solution the service life being negligibly increased in contrast to electrodes which are known until then and are used for plasma torches is largely compensated due to significantly higher production costs.

Therefore, it ~~is~~ the object of the invention desirable to propose electrode elements for plasma torches as well as a suitable production method in which the production costs can be reduced with a simultaneous increase of the service life.

## SUMMARY

According to the invention, ~~this object~~ is solved with an electrode element which comprises the features of claim 1, and a method for the production of same are disclosed ~~according to claim 13~~. Preferred embodiments and improvements of the invention can be achieved with the features denoted in the subordinate claims.

## DETAILED DESCRIPTION

The electrode element according to the invention for the plasma torches as a matter in question comprises at least one core made of a metal or a metal alloy having a work function which is smaller than a metal or metal alloy from which a shell part enclosing at least the one core wherein the one core or even a plurality of cores, respectively, form the actual electrode connected as a cathode.

Between the different materials, thus i.e., between the core surface and the shell part, in an inventive alternative, there is a boundary layer provided in a graded form which is formed from solid solutions of the respective metals and metal alloys, respectively.

In a second alternative for an electrode element according to the invention an intermediate layer made of another metal or a metal alloy having a work function being greater than that of the core material is provided between the core surface and the shell part material wherein the intermediate layer forms a graded transition towards the core and shell part in the form of correspondingly formed boundary layers.
Hafnium and a hafnium alloy, respectively, can be used as a material being particularly appropriate for the core in which

the portion of alloy components should be kept relatively small.

In addition to hafnium and the alloys thereof, respectively, however, tungsten, zirconium or tantalum and alloys of these elements, respectively, can be used as core materials.

Copper and a copper alloy, respectively, is a preferred one material for the shell part.

The intermediate layer again is allowed to be formed from silver or a silver alloy.

The boundary layers existing in an electrode element according to the invention which form each graded transitions of the different materials are not available with the solutions known from the prior art such as with that one described in EP 0 980 197 A2 since this is not possible constructively and inherent inherently in production.

Surprisingly, it turned out that the electrode elements according to the invention are allowed to can be manufactured simply and very reasonably by means of a forming method and/or a joining process using compressive forces (pressing forces) wherein the equivalent boundary layers having graded transitions can be formed without any additional technological processing steps. The extrusion molding or hot isostatic pressing are particularly suitable methods.

Thus, the formation of solid solutions in a boundary layer between the denoted core material and shell part material (e.g. Cu and Hf) has not readily been expected automatically since the difference between the respective melting temperatures of the two metals used for this is significant and amounts to appr. 1000 K. With the solution according to

the invention solid solutions made of copper and hafnium can be formed according to an alternative of an electrode element according to the invention with abandonment to an intermediate layer such that an graded transition, in particular for the electrical conductivity and the thermal conductivity can be achieved not only punctually but over the entire surface to be available.

As the primary products for one core or else multiple cores, the shell part and/or an intermediate layer bar-shaped, wire-shaped or sleeve-shaped elements made of the respective metals and metal alloys, respectively, can be used which are then worked into an electrode element according to the invention by means of extrusion molding.

However, it is also possible to employ the respective metal and metal alloy, respectively, in powder form for these elements. In particular for the formation of the intermediate layer use of powdery silver is particularly favourable. Thus, the spacing between a sleeve-shaped copper part and at least one bar-shaped and wire-shaped element, respectively, forming the core can be filled with a silver powder, and the appropriate intermediate layer is allowed to form with a respective graded transition towards the core surface and towards the shell part due to compressing forces which have an effect during extrusion molding. In the boundary layers a mixing zone being obtainable by means of the individual granules of the powdery starting material will be formed from the respective two metals and metal alloys, respectively, which is homogeneous over the entire surface being available.

Another possibility is in that appropriate powders are used for the core and shell part as well. The starting powders used are then allowed to be fabricated by means of compression molding, preferably cold isostatic pressing each individually

and successively, respectively, one after another into primary products ensuring a sufficient strength for the subsequent extrusion molding process, and subsequently an electrode element according to the invention can be formed by extrusion molding.

For the one core or else a plurality of cores, bar-shaped elements having a circular cross-section can be employed as a primary product.

However, it is also possible to employ such elements having a circular cross-section which are hollow in the interior, and accordingly shaped as a sleeve. This cavity is then allowed to be filled again before extrusion molding with a powder of a metal and a metal alloy, respectively, which have a work function being higher than that of the core material.

However, for the formation of the cores forming the actual electrodes, elements can also be used the cross-sections of which are star-shaped. Such a star-shaped element is then allowed to have three or even a plurality of cross-pieces which are oriented each in equal angular distances to each other, and as a result an enlargement of the respective transition surfaces having the low electrical and thermal transition resistances connected therewith between the core and shell part and boundary layer, respectively, is obtainable.

However, a core is also allowed to be formed from a plurality of wire-shaped elements twisted with each other, similar to stranded wires which are frequently used with electric lines. A core thus formed by drilling of wire-shaped elements enlarges the contact surface and simultaneously the advantageous graduating effect as well.

If several cores should be available with an electrode element according to the invention, thus it is advantageous to arrange the electrodes them in a discrete and equidistant manner to each other, wherein the electrodes they are embedded each into the shell part material using interposition of an intermediate layer, as the case may be.

Advantageously, before the extrusion molding preheating up to a temperature of at least 400 °C should be carried out to reduce the stress of the extrusion molding tool, in particular. However, such preheating has also a positive effect on the formation of solid solution and diffusion processes, respectively, which thus can take place almost certainly with the relatively high compressive forces acting simultaneously during the extrusion molding. An electrode element according to the invention provides low thermal and electrical transition resistances as a result of the more intimate contact with the graded transitions of the different metals and metal alloys, respectively, of the individual elements such that it is allowed to counteract the problem of anodic corrosion, and the service life can be increased significantly. Accordingly, not only the production costs for the electrode elements as such but also the running costs of a correspondingly equipped plasma torch are significantly reduced with the final user.

Also the electrode elements produced with the method according to the invention in which intermediate layers made of silver and silver alloys, respectively, are employed can be produced cost-effective since such intermediate layers are allowed to be formed with a significantly lower layer thickness such that the expensive use of silver can be reduced, accordingly.

As already intimated, a sleeve-shaped copper element can be used for the formation of a shell part. At the same time, at

least one rod-shaped element for example made of hafnium and extending over the entire length of the copper sleeve can be introduced in the interior thereof. As a result, such a copper sleeve is allowed to have an outer diameter of 12 mm, for example, and the free cross-section in the interior of such a copper sleeve is allowed to have a diameter of 1.5 mm. After appropriately preheating, a section for electrode elements according to the invention is then produced by means of extrusion molding which merely has still to be cut to length and another joining and assembly processes are not necessary anymore. An electrode element thus obtained has even to be inserted then into an appropriate plasma torch wherein such a plasma torch can also be formed such that a certain part of such an electrode element which is arranged inside of a plasma torch is allowed to be immediately passed by a cooling agent for dissipating heat.

However, instead of a rod-shaped hafnium element also several hafnium wires preferably being twisted with each other can be introduced into such a copper sleeve wherein the inner diameter of the copper sleeve and the greatest extension of such a core type preliminary element should be dimensioned such that a space remains which can be filled with a silver powder and a silver powder alloy, respectively.

Such a silver powder forming an intermediate layer should also be employed, if possible, when a core which has not the shape of a rotationally symmetric cross-section, or a sleeve-shaped core are to be formed.

However, for example, it is also possible for a rod-shaped element made of hafnium to be provided on its outer surface towards the shell part material with a layer of silver powder formed substantially from silver powder. For example, such a powder can be deposited in the form of a suspension, and be

solidified on the surface of the rod-shaped hafnium element, for example, such as by means of compression molding or can be subjected to sintering. Then, in the last mentioned case, in the suspension containing the silver powder also an organic binding agent is allowed to be included which can be expelled thermally upon sintering.

A rod-shaped element provided with such a silver layer is then allowed to be introduced into a sleeve-shaped copper element again, and thus an electrode element according to the invention can be produced by means of extrusion molding.

However, the electrode element according to the invention can also be improved in that in order to allow this to be connected with a sleeve-shaped element by the formation of a respective contour wherein preferably an external thread can be chosen. Such a sleeve-shaped element which is preferably made of copper can then be repeatedly used again, and thus merely replacement of the correspondingly smaller dimensioned electrode element is required in more or less great intervals. As a result, the electrode element is screwed into a sleeve-shaped element and screwed out of it, respectively, with the thread formed on its outer shell surface as a contour shape.

Since a high thermal load takes place as already mentioned in the general part of the specification above, and since intensive cooling is required, the element according to the invention can also be formed and produced such that a single-sided open cavity has been formed within the shell part. This cavity is allowed to be combined with the filling system of a plasma torch such that the cooling medium, preferably such as water, for dissipating heat is allowed to immediately pass into this cavity.

Advantageously, the formation of such a cavity can be formed by means of backward extrusion. With this method it is possible to avoid metal cutting as well. Backward extrusion is a subsequent processing step on an electrode element, the production of which has been previously described. At the same time an electrode element is manufactured as a primary product the length of which is kept shorter than the finished electrode element having the cavity, and the outer diameter of which is kept greater than that. Upon the backward extrusion a tool with a mandrel predetermining the shape and size of the respective cavity is used, and almost solely the shell part made of copper is worked because of the significantly higher rheological properties.

## Claims

1. An electrode element for plasma torches, in which at least one core forming the actual electrode connected as a cathode is made of a metal or a metal alloy having a smaller work function is enclosed by a shell part made of a metal or a metal alloy having a greater work function and thermal conductivity,
characterized in that the boundary layer between said core surface and said shell part is formed in a graded shape of solid solutions of said two metals or metal alloys, or

an intermediate layer formed from another metal or a metal alloy having a work function being greater than that of said core material forms toward said core surface and toward said shell part each with its boundary layers a graded transition.

2. An electrode element according to claim 1,
characterized in that said core is formed from hafnium or a hafnium alloy.

3. An electrode element according to claim 1,
characterized in that said core is formed from tungsten, zirconium or tantalum or an alloy of these elements.

4. An electrode element according to any one of the preceding claims, characterized in that said shell part is formed from copper or a copper alloy.

5. An electrode element according to any one of the preceding claims, characterized in that said intermediate layer is formed from silver or a silver alloy.

6. An electrode element according to any one of the preceding claims, characterized in that said core is formed in a rod-shaped manner with a circular cross-section.

7. An electrode element according to any one of the preceding claims, characterized in that said core is formed from a plurality of wire-shaped elements being twisted with each other.

8. An electrode element according to any one of the preceding claims, characterized in that said core comprises a star-shaped, annular cross-section or in that said cross-section is cross-shaped.

9. An electrode element according to any one of the preceding claims, characterized in that several cores being separately arranged form said electrode.

10. An electrode element according to any one of the preceding claims, characterized in that said intermediate layer is formed from a powder.

11. An electrode element according to any one of the preceding claims, characterized in that within said shell part a single-sided open cavity which is connected to a cooling is formed.

12. An electrode element according to any one of the preceding claims, characterized in that said electrode element is replaceably connected to a sleeve-shaped portion of copper.

13. A method for the production of an electrode element for plasma torches, characterized in that said electrode element is manufactured by the application of compressive forces with a shaping method and/or a joining method in the form of a sleeve-shaped part which forms a shell part and is made of a metal or a metal alloy having a higher work function and a higher thermal conductivity and electrical conductivity into which at least one core element made of a metal or a metal alloy having a lower work function which forms said electrode and is connected as a cathode has been introduced.

14. A method according to claim 13,
characterized in that said electrode element is manufactured by extrusion molding or hot isostatic pressing.

15. A method according to claim 13 or claim 14, characterized in that preheating at least up to 400 °C is carried out before extrusion molding.

16. A method according to any one of claims 13 to 15, characterized in that before extrusion molding said cavity between said sleeve-shaped part and said core element is filled for the formation of said intermediate layer with another powdery metal or a metal alloy having a work function, thermal conductivity and electrical conductivity being higher than said core material.

17. A method according to any one of claims 13 to 16, characterized in that, for the formation of said one core several wire-shaped elements are twisted with each other.

18. A method according to any one of claims 13 to 17, characterized in that before extrusion molding said cavity of said core element formed in said sleeve shape is filled with a powder of a metal or a metal alloy which has a work function being higher than said core material.

19. A method according to any one of claims 13 to 18, characterized in that said shell part, said core and/or said intermediate layer form one or one common primary product each from a powder by means of a compression molding method, and said electrode element is manufactured from one primary product or several primary products by means of extrusion molding.

20. A method according to claim 13, characterized in that said primary product(s) is (are) manufactured by cold isostatic pressing.

21. A method according to any one of claims 13 to 20, characterized in that a contour is formed on the outer circumferential surface of said shell part for a positive joint with a sleeve-shaped copper part.

22. A method according to any one of claims 13 to 21, characterized in that a single-sided open cavity is formed within said shell part by means of backward extrusion.

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## Abstract

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The invention relates to an electrode element for plasma torches and a production method for such electrode elements. According to the set object, it should be possible to reduce the production costs while simultaneously increasing the service life. The electrode element according to the invention for plasma torches then comprises includes ~~at least~~ one core which is made of a metal or a metal alloy having a smaller work function, and forms the actual electrode connected as a cathode. This core is enclosed by a shell part which is made of a metal or a metal alloy having a greater work function and thermal conductivity. Between the core surface and the shell part there are provided a boundary layer in the a graded form, which is made up of solid solutions of the two metals or metal alloys, or an intermediate layer toward the core surface and toward the shell part, which is made of another metal or a metal alloy having a work function being greater than that of the core material wherein the boundary layer of the intermediate layer form a graded transition.